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FREE-SPINNING-TUNNEL TESTS OF A 1/23.75-SCALE MODEL OF THE DOUGLAS DC-3 AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces

Bureau of Aeronautics, Navy Department

and

Civil Aeronautics Authority

FREE-SPINNING-TUNNEL TESTS OF A 1/23.75-SCALE MODEL OF THE DOUGLAS DC-3 AIRPLANE

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SUMMARY

A model of the Douglas DC-3 airplane was tested in the 20-foot free-spinning tunnel for several loading conditions. The load factor for the airplane as a whole, the load on the horizontal tail, and the force required to start moving the elevator downward were estimated for some of the steady spins. The altitude loss in the recovery from a spin and in the pull-out from the ensuing dive was also determined. Although recoveries were fairly rapid, it was concluded that, because of possible structural overload and high control forces, it would not be safe to put the DC-3 airplane into an established spin.

INTRODUCTION

Considerable interest has developed in recent years in the spin characteristics of transport-type airplanes, of which the Douglas DC-3 is a representative example. Serious accidents have occurred, which investigators concluded might have resulted from entry into spins. Air-line pilots have reported inadvertent spins on regular air-line equipment on quite a few occasions.

It is understood that some air lines check pilot personnel in one-turn spins on standard air-line transports. Rapid recoveries were obtained when rudder and elevator were reversed. There is, however, little additional information concerning the spin characteristics of transport-type aircraft, although models of some twin-engine military airplanes have been tested in the NACA 15-foot and 20-foot free-spinning tunnels.

The Civil Aeronautics Board in a recent report on a transport accident (reference 1) recommended that a model of the DC-3 airplane be tested in the NACA free-spinning tunnel. A 1/23.75-scale model was so tested and the results are given in the present report.

The data obtained in the tests have been evaluated to give the attitudes, the velocities, and the load factors, during the established spins, as well as the relative effectiveness of various control manipulations for recovery. Information on load factors in spins was requested by the Civil Aeronautics Authority for use in connection with formulation of structural-design requirements.

All tests were for the clean condition; that is, flaps and landing gear were not simulated. The effects of variation in the loading condition were determined and two equivalent test altitudes were covered. Brief tests of inverted spins were also made.

APPARATUS AND MODEL

The tests were performed in the NACA 20-foot free-spinning tunnel, the operation of which is similar to that of the 15-foot free-spinning tunnel as described in reference 2.

The model, which was 4 feet in span, was constructed by the NACA. Lightness in structural weight was obtained by using balsa ribs covered with doped paper in the construction of the fuselage and wings. The nacelles, wing tips, and tail surfaces were of balsa. Lead weights were installed in suitable locations to bring the total weight, the center of gravity, and the moments of inertia to the desired scaled-down values. An electrically operated remote-control mechanism was installed in the model to move the control surfaces during the recovery tests. Photographs of the model are given as figures 1 to 4. These photographs do not show the ailerons which were installed later.

The exact control deflections for the subject airplane were not known when the tests were started and the following normal maximum control deflections were arbitrarily used (a later check showed that the values used for the rudder and elevator deflections were correct and that those for the ailerons were in error by only a few deg):

Rudder . . . . 30° left, 30° right
Elevator . . . . 30° up, 20° down
Aileron . . . . 25° up, 15° down

TEST CONDITIONS

Values of the moments of inertia of the DC-3 airplane were not available at the time the investigation was started and the necessary values were therefore computed from weight and balance information prepared by the Douglas Aircraft Company.

Similar mass-distribution data were subsequently received from the Douglas Aircraft Company for the model DST, which is essentially similar to the DC-3 airplane, except for passenger arrangements.

The values computed by the NACA for the DC-3 airplane were for the maximum passenger condition: 21 passengers, pilot, co-pilot, stewardess, and de-icing equipment. This loading condition will hereinafter be referred to as the "normal loading."

The data for the DST are for the "sleeper" condition with pilot, co-pilot, stewardess, and 14 passengers.

A comparison of the two sets of data, for landing gear retracted, follows:

	DC-3	DST
Weight, pounds	25,554	24,000
$x/\bar{c}$	0.247	0.204
$z/\bar{c}$	-0.116	-0.112
I_X, slug-feet^2	66,670	63,930
I_Y, slug-feet^2	91,690	92,970
I_Z, slug-feet^2	150,400	145,300
$\dfrac{k_X^2 - k_Y^2}{b^2}$	-0.00347	-0.00432
$\dfrac{k_Y^2 - k_Z^2}{b^2}$	-0.00823	-0.00780
$\dfrac{k_Z^2 - k_X^2}{b^2}$	0.01167	0.01211
b, feet	95	95

where

$\bar{c}$	mean aerodynamic chord
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)
I_X, I_Y, I_Z	moments of inertia about body axes X, Y, and Z, respectively
k_X, k_Y, k_Z	radii of gyration about body axes X, Y, and Z, respectively
b	wing span

The agreement between the two sets of values was considered reasonable and the computed values for the DC-3 were taken as appropriate for the model tests.

It will be noted that the mass distribution as measured by the relative values of I_X and I_Y was not like that of the average multiengine airplane. (See reference 3.) While for most multiengine military airplanes I_X is greater than I_Y, for the DC-3 the reverse was true. This condition evidently resulted from the relatively greater utilization of the fuselage for carrying items of load.

For the main portion of the tests, which were performed at 10,000 feet equivalent test altitude (ρ = 0.001756 slug per cu ft), the model loading condition simulated the scaled-down values for the DC-3 airplane maximum passenger condition within the following limits:

Weight		$\pm$1 percent
Center-of-gravity location		0 to 0.03$\bar{c}$ rearward of normal
Moments of inertia	I_X	3 percent low to 11 percent high
	I_Y	10 percent low to 4 percent high
	I_Z	6 percent low to 11 percent high

Some preliminary tests were made at an equivalent test altitude of 2500 feet (ρ = 0.002209 slug per cu ft). The model was ballasted to represent a preliminary estimate of the mass distribution of the full-scale airplane, referred to hereinafter as the "preliminary normal load," which was as follows:

Weight, pounds	25,554
$x/\bar{c}$	0.252
$z/\bar{c}$	-0.115
I_X, slug-feet^2	85,260
I_Y, slug-feet^2	92,310
I_Z, slug-feet^2	169,400

The model loading was held to the values given within the following limits:

Weight		±1 percent
Center-of-gravity location		0.01$\bar{c}$ forward to 0.01$\bar{c}$ rearward of normal
Moments of inertia	I_X	14 percent low to 4 percent low
	I_Y	5 percent low to 5 percent high
	I_Z	8 percent low to 2 percent high

The model was originally ballasted to closer limits than shown but, in the course of testing, there were some weight changes after damage and repair.

Information on various operating load conditions for the DC-3 was obtained from weight and balance estimates prepared by the Douglas Aircraft Company.

The principal load conditions, other than the maximum passenger condition, with estimated corresponding mass characteristics (the estimated center-of-gravity locations are approx. 0.03$\bar{c}$ rearward of those given by the Douglas Aircraft Company) are as follows:

Condition	Weight (lb)	$x/\bar{c}$	Moment of inertia (slug-ft^2)		
			I_X	I_Y	I_Z
Max. forward c.g.	20,886	0.148	66,280	77,860	136,100
Max. rearward c.g.	21,883	.314	63,340	93,610	150,000
600 gal. fuel	25,554	.235	68,360	92,580	149,900
Max. fuel	25,554	.280	68,100	94,400	155,000
Max. cargo	25,451	.216	68,480	105,000	165,400

An investigation was made of the effects of changes in mass distribution on the spin characteristics of the model. The center-of-gravity location and the longitudinal and lateral mass distributions were varied through wide limits but the alternate flight load conditions were not specifically tested.

All tests were for the clean condition: wheels retracted and flaps up.

RESULTS AND PRECISION

The results which are presented in charts 1 to 5 and in table 1 were obtained as described in reference 2. The angle α is measured between the thrust axis and the vertical and is approximately equal to the angle of attack in the plane of symmetry. The angle ϕ is the angle between the lateral, that is, span axis and the horizontal and is positive when the right wing is down. The full-scale rate of descent V is given in feet per second true airspeed and the full-scale angular velocity Ω is given in revolutions per second. The load factor for the airplane as a whole as shown on the charts is computed as $1/\sin \alpha$ on the assumption that the resultant aerodynamic force in a spin is approximately normal to the airplane XY plane and that the vertical component of this force must equal the weight of the airplane. (The wing has 2° of incidence.) The sideslip can be computed as ϕ minus the helix angle. The helix angle was approximately -6° for left spins and 8° for right spins. Recovery was generally attempted by reversal of the rudder from full with to full against the spin although other control manipulations were also tried.

The precision of the test results is believed to be within the following limits:

V, percent	± 2
Ω, percent	± 2
α, degrees	± 1
ϕ, degrees	± 1
Turns for recovery	$\pm 1/4$

The preceding limits may be exceeded for certain cases in which it is difficult to handle the model in the tunnel because of the wandering or oscillatory nature of the spin.

Comparison of model and airplane spin results (reference 2 and unpublished data) indicated that, because of scale and tunnel effects, lack of detail in the model, and differences in operators' techniques, the spin-tunnel results are not always in complete agreement with full-scale spinning data. In general, for a given loading condition and control setting, the model steady-spin results have shown a somewhat smaller angle of attack, a somewhat higher rate of descent, and at a given angle of attack from 5° to 10° more outward sideslip. The comparison showed that 80 percent of the model-recovery tests predicted satisfactorily the corresponding full-scale recoveries and that 10 percent overestimated and 10 percent underestimated the full-scale recoveries.

DISCUSSION

In the presentation of the results, the general spin characteristics and the effects of variations in loading and changes in control position are discussed first and a detailed analysis and explanation of certain points is given later. The greater part of the results were obtained with the model loaded for an equivalent test altitude of 10,000 feet. Tests with this loading indicated that, because of some asymmetry in the model resulting from damage during earlier tests with the preliminary normal loading, left spins were somewhat flatter than right spins. The regular test program was conducted with spins made to the left, giving slightly slower recoveries and somewhat smaller load factors than would have been obtained for the opposite direction.

Equivalent Test Altitude of 10,000 Feet

Normal loading.- The general spin and recovery characteristics for the normal loading are shown in chart 1.

For the normal control configuration for spinning (rudder with the spin, elevator up, and ailerons neutral) the model spun steeply ($\alpha = 35^{\circ}$), with corresponding full-scale rate of descent of 172 feet per second true airspeed and full-scale angular velocity of 0.29 rps (approximately 3.5 sec for 1 turn). The load factor for the airplane during this spin was 1.73. Recovery by reversal of the rudder was rapid, occurring in 1 turn. After recovery from the spin, the model descended in a steep glide with a small amount of rolling motion.

With the elevator set at neutral, the spin was flatter and the rate of descent and the load factor were lower. The rate of rotation increased but there was no effect on the rapidity of recovery. After the rotation ceased, the model dived straight down. Setting the elevator down had only little effect on the spin characteristics. In the last portion of the recovery with this elevator setting, the model pitched over on its back and glided inverted.

It was noticed during the test program that recoveries were generally similar to the three types just described. The motion during the recovery was determined principally by the elevator deflection during the recovery. The three types are illustrated in figures 5, 6, and 7.

The aileron-with spins (left aileron up and right aileron down in a left spin) were similar to the elevator-up aileron-neutral spin and recoveries were rapid. The model was not tested with the elevator up and ailerons against the spin because of the excessive oscillation with this control configuration. A steady spin was obtained with this elevator-aileron configuration when the rudder deflection was increased to 35° with the spin. Recovery from this spin was rapid, thereby indicatin that recovery from the spin with the normal rudder setting would have been rapid. With the elevator neutral and down, the aileron-against spins were slightly flatter than the corresponding spins with ailerons neutral, but recovery was still satisfactory.

The model would not spin with the elevator set at neutral or down and the rudder neutral. When launched with elevator up, the model descended rapidly and struck the net while still rotating.

Loading variations.- A beneficial effect when the elevator was neutral or down was apparent when mass was added along the wings (chart 2). Although the model generally would not spin with these elevator settings, recovery was retarded when the elevator was up and load factors higher than those previously obtained were indicated when the elevator was up and the ailerons were neutral.

The tests indicated that, with a large increase in load along the wings, reversal of the rudder alone would be inadequate for satisfactory recovery and that it would be essential to put the stick forward.

The effect of changing the mass distribution along the fuselage is shown in chart 3. Removing mass from the fuselage gave results similar to those previously obtained by adding mass along the wings. Adding mass along the fuselage was detrimental for spins with the elevator neutral or down and the ailerons neutral or against the spin. For these cases the spins were flat and recoveries were too slow to be satisfactory.

With this excess loading along the fuselage, recovery tests were made with other control manipulations. In general, merely neutralizing the rudder was not satisfactory (chart 3) and releasing the rudder (table 1) was less effective than neutralizing the rudder. These results indicated that the rudder must be completely reversed for most satisfactory recovery and that a definite force must be applied to accomplish the reversal.

The results of tests made with large changes in the center-of-gravity location, covering a range greater than that indicated for the full-scale airplane, are presented in chart 4. Movement of the center of gravity 15 percent of the mean aerodynamic chord forward of normal, that is, to 10 percent of the mean aerodynamic chord, was advantageous in that the model would spin only when the elevator was up and the ailerons were neutral or with the spin. Recovery from the aileron-with spin was rapid and it is believed that recovery from the aileron-neutral spin would also have been rapid. There was no appreciable effect of moving the center of gravity 6 percent of the mean aerodynamic chord rearward of normal, that is, to 31 percent of the mean aerodynamic chord.

The preceding discussion shows that deflecting the ailerons in a given direction may be beneficial or detrimental, depending on the exact loading conditions, and that the effectiveness of the elevator will vary with the loading. The calculated values for the basic moments of inertia may be in error by as much as ±8 percent and, in any event, the loading may change between flights or during a flight as a result of consumption of fuel or redistribution of items of useful load. It therefore seems desirable generally to hold the ailerons neutral throughout the spin and to attempt recovery by first reversing the rudder and then pushing the elevator toward neutral.

The principal flight load conditions differ from the normal condition by some combination of changes in center-of-gravity location and in loading along the wing or fuselage, such as those tested on the model. The model tests can be used in predicting the results for the alternate flight loadings.

It appears that there will be little difference between spins with the normal loading and spins with any of the following loadings:

(a) Maximum rearward center of gravity (airplane may descend more slowly owing to lighter weight)

(b) Maximum fuel condition

(c) 600 gallons of fuel condition

With maximum forward center of gravity, the airplane will probably spin only when the elevator is up. These spins will be steep and will, consequently, have high load factors. With the maximum cargo condition, elevator-up or aileron-with configurations will still give satisfactory recoveries but there will be a tendency for elevator-down and aileron-against control settings to give slow recoveries.

Because of the diversity of attitudes at which the model spun, there was considerable difference in the values of the spin parameters. The maximum and minimum values of some of these parameters are listed below:

	α (deg)	V (ft/sec)	Ω (rps)	Load factor
Max. value	68	206	0.40	2.04
Min. value	29	121	.24	1.08

The high load factors and high rates of descent are obtained for the steepest spins.

Equivalent Test Altitude of 2500 Feet

Erect spins.- For the tests at the 2500-foot equivalent test altitude, the model was ballasted using a preliminary estimate of the moments of inertia. A comparison of these moments of inertia with the final computed values shows that I_X and I_Z for the tests at 2500-foot equivalent alitude were about 28 percent I_X too high with the result that the preliminary normal loading had relatively more mass distributed along the wings than the final loading.

For the initial tests, the model was practically symmetrical and left spins were quite similar to right spins. It has been previously indicated that, in the course of the preliminary testing, the model later became slightly asymmetrical as a result of damage and repair and that spins to the left became somewhat flatter and steadier than to the right. The results for 2500-foot equivalent test altitude were all for right spins and are presented on chart 5 (ailerons were not installed for these tests).

There were two types of spin for the elevator-up configuration when the model was in the preliminary normal loading condition. Both spins were steep and recoveries were rapid. The model would not spin with elevator neutral or down. There was no effect on recovery of an increase in the mass distribution along the wings but the elevator-up spin was very steep and the load factor increased to 2.4. There was no effect of moderate changes in the center of gravity but the model would not spin when the center of gravity was 15 percent of the mean aerodynamic chord forward of normal, that is, at 10 percent of the mean aerodynamic chord.

Increasing the mass distribution along the fuselage or a combined increase in the mass distribution along the fuselage and a rearward movement of the center of gravity were somewhat detrimental. With either of these loading conditions, the model would spin with the elevator neutral or down. Although some of these spins were relatively flat, recoveries were rapid.

Inverted spins.- The model was launched in a spin with the rotation counterclockwise when viewed from above because this direction was more convenient with the existing control-mechanism installation. Regardless of the rudder or the elevator setting, with ailerons neutral, the model stopped rotating almost immediately after being launched and dived down into the safety net, indicating that it would not spin inverted if the ailerons are neutral.

Effect of altitude.- For the preliminary normal model loading at 2500-foot equivalent test altitude, the distribution of mass along the span was considerably greater than that at 10,000-foot equivalent test altitude. As previously mentioned, an increase in the mass distribution along the wing at 10,000-foot equivalent altitude led to a condition in which elevator-down deflections were favorable in that the model would not spin. It is felt, therefore, that the apparent change from a condition in which the model would not spin at 2500-foot equivalent altitude with the elevator neutral or down to relatively flat spins at 10,000-foot equivalent altitude is caused by the difference in the loading along the wings and that the change in equivalent altitude did not substantially affect the spin characteristics.

ANALYSIS

In the preceding discussion, the general characteristics of the spins of the DC-3 model have been described. Certain features, such as the airplane path and motion, the acting forces, and the load factors, are believed to be of sufficient interest to warrant detailed consideration. Some of these points are of especial importance in structural design considerations.

Motion in a Typical Steep Spin

Considerable interest has been expressed in the motion of the DC-3 airplane during a spin and during recovery therefrom. The normal spin, with elevator up and ailerons neutral, was fairly steep ($\alpha = 35^{\circ}$). For this spin, which is typical of the steeper spins obtained, the attitude and the rotational motion of the model are shown by motion pictures in figure 8. Pictures of a recovery from a similar spin are shown in figure 5. (Camera speed for the photographs of figs. 8 and 10 was 64 frames per sec and for those of figs. 5 to 7 was 32 frames per sec. The horizontal line in the background of these pictures is the tunnel horizontal reference line.)

In the interpretation of these photographs, it must be appreciated that during the steady spin the model remained at a fixed level because it was spinning in a column of air that was rising at 35 feet per second, corresponding to 172 feet per second full scale, and that during the recovery the airspeed was increased above this value to compensate partly for the increased rate of descent of the model.

As an aid in visualizing the actual motion, figure 9 has been prepared showing the full-scale altitude loss per turn, radius, and estimated recovery motion for the same spin. During the steady spin the full-scale altitude loss per turn was about 600 feet but, after the rudder was reversed, the altitude loss was about 1000 feet for the remaining turn. At this point the rotation had stopped but the rate of descent had increased to 254 feet per second true airspeed. The path during the recovery was estimated from the motion-picture record which showed the increase in rate of descent and the radius of spin during the recovery.

As has been previously noted, the model flight path during recovery is dependent on the elevator setting. For the recovery shown in figures 5 and 9, the elevator was held full up when the rudder was reversed and the flight path after recovery had a noticeable horizontal component. If the elevator had been neutralized when the rudder was reversed, the model would have gone down in a vertical dive after the rotation ceased (fig. 6). A combined reversal of the rudder and elevator would have led to a condition in which the model would have been in an inverted dive upon recovery from the spin (fig. 7). From the foregoing discussion, it is apparent that for this airplane if the elevator is kept, for example, about 10° above the neutral position recovery will be smoother than if the elevator is down.

Motion in a Flat Spin

Under certain conditions of loading and control deflections, flat spins may be encountered with the DC-3. The angles of attack for the flat spins on the model were as high as 68°.

Motion pictures of a typical flat spin are shown in figure 10. For this spin the angle of attack was 63°. The rate of descent had decreased to 121 feet per second true airspeed and the rate of rotation had increased to 0.34 rps. The radius of spin was small, 3.5 feet.

Recoveries from flat spins were generally slower than recoveries from steep spins but the types of flight path after the rotation ceased were still dependent on the elevator deflection and were similar to those previously described.

Force and Moment Coefficients for the Steady Spin

The aerodynamic force and moment coefficients were computed for the spin of figure 8 upon the assumption that the resultant aerodynamic force was perpendicular to the airplane XY plane (approx. the wing-chord plane). The airplane in a spin is in a state of equilibrium and the inertia couples are balanced by opposite aerodynamic couples. The inertia couples were obtained from Euler's equation as follows:

$$\text{Inertia rolling moment} \quad L = (I_Y - I_Z)qr$$

$$\text{Inertia pitching moment} \quad M = (I_Z - I_X)rp$$

$$\text{Inertia yawing moment} \quad N = (I_X - I_Y)pq$$

where p, q, and r are the component angular velocities about tho body axes. In converting these moments to coefficients, the characteristic lengths employed were the wing chord for the pitching moment and the wing span for the rolling and yawing moments.

After completion of the tests in the 20-foot free-spinning tunnel, the model was mounted on the balance in the free-flight tunnel and the lift, the drag, and the pitching-moment coefficients were measured with controls neutral for several angles of attack above the stall. Sideslip was not simulated during the balance tests because it was felt that this factor would have but little effect. The coefficients obtained from the balance data have been corrected to correspond to the control deflections of the model in the spin and are compared to the values computed for the spin of figure 8 as follows:

	Coefficient				
	Lift	Drag	Rolling moment	Pitching moment	Yawing moment
Computed for spin	0.964	1.008	0.00582	-0.476	0.00258
Balance	.840	.671	-------	-.517	-------

The differences between the values of forces and moments for the spinning model and the corresponding values for the model on the balance can be assumed to be principally due to the rotation in the spin. It is evident that the rotation led to a somewhat higher value of the lift coefficient, an appreciably higher value of the drag coefficient, and a smaller nose-down pitching-moment coefficient. These effects of the rotation have also been noted in previous instances.

Structural Loads

Load factors in the steady spin.- The load factors (normal to the thrust axis) in the steady spin have been given on the charts. These load factors were computed as $1/\sin\alpha$ on the assumption that the resultant aerodynamic force in a spin is approximately normal to the body XY plane. A plot of these load factors against angle of attack is given in figure 11. R is the resultant aerodynamic force. Load factors computed as $1/\sin(\alpha + 2)$ have also been plotted corresponding to the more accurate assumption that the resultant force is normal to the chord of the wing (wing incidence was 2°).

An experimental check on the accuracy of the assumption regarding the inclination of the resultant force can be made by directly measuring the radius of spin or by measuring the ratio of lift to drag for the complete model.

Measured radii obtained from motion pictures were smaller than computed values, especially for the steeper spins. Based on the measured radii of spin the inclination of the resultant force was computed to be from 0° to 8° rearward of the body normal or Z axis. The correspondingly lower load factors are also presented in figure 11.

In order to obtain additional information on the inclination of resultant force above the stall, the balance measurements on the stationary model were used. The measured lift/drag corresponded to an inclination of resultant force varying from 0° to 3° rearward of the normal axis. The load factors (fig. 11) for a spin with these values for lift/drag would vary from $1/\sin(\alpha + 2)$ for the normal spin attitude to $1/\sin \alpha$ for a very steep spin.

The agreement between the results from the different methods of computing the load factor is regarded as fair for steep spins and good for flat spins. The values for the load factors considered equal to $1/\sin \alpha$ are the most conservative (highest) and those based on the measured radii of spins are the lowest. These results indicate that the load factor of the DC-3 airplane in a spin will probably not exceed a value of 3.0.

In order to investigate further the aerodynamic loads likely to be encountered during a sudden change in attitude, the normal-force coefficients for the DC-3 model were computed from the free-flight tunnel balance data. The normal-force coefficient, that is, force coefficient along the body Z axis, decreased gradually from a value of 1.20 at an angle of attack α of 35° to 1.05 at the stall and then decreased rapidly as α decreased. It can therefore be inferred that the airplane will not experience a peak load factor if it is suddenly nosed down from a condition above the stall to an angle of attack below the stall, unless the rate of descent increases very sharply.

Relation of velocity gained and altitude lost to load factor in recovery from a dive.- When the spin rotation ceases, the airplane is generally in a steep dive and is gaining speed. The pilot has the alternative of pulling the airplane sharply out of the dive, a procedure that will give rise to high load factors, or pulling the airplane out gradually with moderate load factors but with greater loss in altitude and greater gain in velocity. Reference 4 gives charts for determining, for a given type of pull-out (that is, imposed load factor variation), the altitude lost and the velocity gained in the return to level flight in terms of the velocity and the flight path at the start of the pull-out. By use of these charts the altitude lost and the velocity gained in the dive have been determined for a recovery similar to that shown in figure 9. The dive was assumed to start with a velocity of 173 miles per hour true airspeed (149 mph indicated airspeed) at an altitude of 8500 feet and it was arbitrarily considered that the initial path was vertical. The drag parameter K was assumed to have a value of 0.030 and the load factor was taken to increase linearly from 0 to 2 in 2 seconds and then to remain constant until level flight was attained. The velocity increment obtained was 110 miles per hour indicated airspeed, giving a final velocity of 285 miles per hour true airspeed (259 mph indicated airspeed), and the altitude loss was approximately 2000 feet. These values are subject to a small correction because the mean altitude during the recovery from the dive was somewhat higher than the value used in reference 4.

Computations of a similar nature have been made by the Douglas Aircraft Company, in which the assumed conditions were the same except that the initial velocity was taken as 151 miles per hour true airspeed (130 mph indicated airspeed) and the initial altitude was 10,000 feet. The computed final velocity was 299 miles per hour true airspeed (266 mph indicated airspeed) with an altitude loss of 2340 feet in a time interval of 13 seconds. The computed results from the two sources are thus in good agreement.

As the placard dive speed of the DC-3 airplane is 262 miles per hour, it is obvious that skillful piloting is essential to avoid on the one hand exceeding a safe load factor and on the other hand exceeding the allowable maximum airspeed.

The preceding example was for an initial velocity of 173 miles per hour true airspeed, based on the test results for the normal loading. It should be appreciated that, for other loadings, the initial velocities and the maximum velocities during the pull-outs might be noticeably higher.

The charts in reference 4 show that the initial flight path has a considerable effect on both the velocity gained and the altitude lost. It appears that the flatter initial flight paths give smaller increments of velocity and smaller altitude losses than the steeper flight paths. The motion of the DC-3 model after the rotation ceased depended on the elevator deflection during the recovery from the spin, with elevator-up deflections giving flight paths with a noticeable horizontal component whereas elevator neutral or lower gave vertical flight paths. Thus, it is evident that reductions in the velocity gained and the altitude lost in the return to level flight following the recovery from the spin may be secured by holding the elevator above the neutral position during the recovery from the spin.

<u>Altitude loss in recovery from spins</u>.- Figure 9 indicates that there is an altitude loss of approximately 1000 feet from the time the controls are moved until the spin rotation ceases. It has previously been shown that an additional 2000 to 2500 feet are then required to return to level flight without imposing excessive structural loads on the airplane. Approximately 3000 feet are, therefore, necessary to regain normal flight attitudes from a spin.

<u>Asymmetrical loads</u>.- Attention is called to the fact that the load factors previously given have been the load factors for the airplane as a whole. The asymmetrical air flow over the airplane in a spin may give excessively high local loads. Some information on the pressure

distribution and the local loads on the wings and tail in a spin may be obtained from the results of flight tests of an older fighter-type aircraft (reference 5). This pressure-distribution investigation showed asymmetrical loading on the wings and tail plane with high local loads at some points. The danger of structural failure from high local loads must therefore not be overlooked.

As an aid in visualizing the local air flow over the different parts of the airplane, computed approximate velocity components (body axes) of the relative wind at the center of gravity, the wing tips, and the tail of the DC-3 model for the spin of figure 8 are shown in figure 12. It is apparent from this figure that, although the right (outer) wing tip is not stalled, the angle of attack increases linearly to a large value (35°) at the plane of symmetry and to an extremely large value at the inner wing tip. The horizontal tail plane is also stalled and there is considerable outward sideslip at the tail.

In estimating loads on the vertical tail it should be remembered that the vertical surfaces will be partly "blanketed" by the outboard half of the horizontal tail plane; that is, the tail plane will cast an "aerodynamic shadow" on the vertical tail. Smoke-flow pictures showing this blanketing for a smaller airplane in a spin are presented in reference 6.

Tail load.- An attempt was made to approximate the load on the tail for the spin of figure 8 by deducting the estimated pitching moments due to the wing and fuselage from the previously evaluated pitching moment for the complete model and expressing the remaining moment in terms of the tail load.

Information on the pitching moment of the DC-3 wing and fuselage was not available but estimates, based on data for other models, led to values for the load acting upward on the tail of the order of 3000 or 4000 pounds (15 and 20 lb/sq ft) when the elevator was up. The flight investigation described in reference 5 shows that in a spin the peak local pressure on the tail plane may be considerably in excess of the average value. Wind-tunnel test data giving tail lift coefficients on a pursuit-airplane tail unit, similar in section and plan form of stabilizer and elevator to that of the DC-3, at high angles of attack (reference 7) were used in getting a check value of the probable order of magnitude of the load on the DC-3 airplane tail plane in a spin. The value thus obtained was about 2000 pounds for elevator full up.

Similar estimates of the tail loads in the same spin but with elevator at neutral gave tail-plane loads about twice the values obtained for elevator full up.

Control Forces

The results of the recovery tests herein presented indicate the effectiveness of the controls without regard to the forces applied. As model results were obtained by applying sufficient hinge moment to move the controls fully and rapidly, it would be necessary for full-scale tests to be made in the same manner in order for results to be comparable with the tunnel results.

The problem now arises as to whether the pilot can exert sufficient force on the wheel and on the rudder pedal to move the controls in such a manner. Computations were made of the stick force required to start moving the elevator down for the spin of figure 8. For these computations, hinge-moment coefficient values were taken from reference 7 and it was assumed that the elevator was completely mass balanced. This force was about 160 pounds which, although high, is within the physical capability of a pilot who is using two hands on the wheel (reference 8).

Reference 7 indicates that the elevator-control force can be materially reduced by setting the trailing edge of the trimming tab full up when the elevator is up.

The force required to move the elevator downward would be appreciably greater when the elevator is neutral and it is doubtful whether a single pilot could move the elevator to the neutral position even with the assistance of the trimming tab when the DC-3 airplane is in a spin.

Model tests indicated that when the rudder was released it would float toward neutral but it was impossible to determine the final position. The rudder forces and the aileron forces were not computed but it is felt that, under certain conditions, they too might be high. The pilot will probably experience difficulty in moving some of the controls when the airplane is in a spin and the possibility exists that the forces may be so great that the necessary recovery manipulation of the controls cannot be performed.

Indicated Airspeed

The accuracy of the indicated pitot airspeed reading for determination of rate of descent of an airplane in a spin is questionable because of several sources of error.

During a spin the fixed pitot tube is not alined with the local air flow because the airplane is rotating and at a large angle of attack. Both the magnitude and the direction of the local air velocity vary along the span. The variation of air flow along the span was indicated in figure 12. If the pitot tube were located well out along the span, particularly on the inboard wing in the spin, there would be a large discrepancy between the indicated airspeed and the true rate of descent. For the usual pitot-tube location under the nose on the DC-3 airplane, the error due directly to the angle of attack and to the rotation of the airplane is probably small in a steep spin. There is, however, a possibility that at this angle of attack there may be an appreciable error owing to the effects of fuselage interference on the local air flow.

CONCLUDING REMARKS

For reasons discussed in the text, it is not considered safe to put the DC-3 airplane into an established spin. The model results indicate the following spin characteristics for the DC-3 airplane with flaps and landing gear retracted:

1. With the maximum passenger loading condition and the normal control configuration for spinning, the spin will be steep, airplane nose down 55° from the horizontal, and the rate of descent will be about 175 feet per second true airspeed. The load factor for the airplane during the established spin will be approximately 1.7. It is recommended that for recovery the rudder be rapidly reversed to full against the spin after which the elevator should be moved down until it is about 10° above the neutral position. The ailerons should be kept neutral. This control manipulation should make the airplane stop spinning after about 1 additional turn. At this point the airplane will be diving at about 170 miles per hour true airspeed. In the subsequent pull-out a load factor of about 2 should be maintained in an attempt to avoid excessive gain in speed while keeping within the normal load-factor range.

2. A flat spin with nose about 40° below horizontal and a rate of descent of 95 miles per hour can also be obtained. This condition can be expected if the elevator is down and the ailerons are against while the rudder is still with the spin.

3. If the recovery is effected while the elevator is above the neutral position, the flight path in the dive will have an appreciable horizontal component. If the elevator is neutral or down, the recovery dive will be vertical and there will be greater probability of exceeding the safe load factor during the pull-outs.

4. For the maximum forward center-of-gravity condition, the airplane will show less tendency to remain in a spin. For the maximum cargo condition, recovery will be adversely affected when the elevator is down and ailerons are against the spin. Results for the remaining operating loadings will be similar to those for the maximum passenger loading.

For all loadings, it is recommended that recovery from the spin be made by fully reversing the rudder, after which the elevator should be moved to about 10° above neutral and the ailerons should be moved to neutral. Merely neutralizing the rudder will not necessarily give recovery.

5. Approximately 3000 feet will be lost during the recovery from the spin and the pull-out from the ensuing dive.

6. The forces necessary to move the controls in a spin may be so high as to require the combined efforts of the pilot and co-pilot. In this connection, it should be noted that the elevator trimming tab can be used effectively to help move the elevator down.

7. Air loads on the horizontal tail plane will be of the order of 3000 to 6000 pounds during the spin.

8. Recovery from inverted spins can probably be effected by neutralizing the ailerons and the rudder.

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Langley Field, Va.

REFERENCES

1. Anon.: Report of the Civil Aeronautics Board of the Investigation of an Accident Involving Civil Aircraft of United States NC 21727 Which Occurred near Vero Beach, Florida, on April 3, 1941. File No. 1325-41, Docket No. SA-35, CAB, Nov. 21, 1941.

2. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. No. 557, 1936.

3. Seidman, Oscar, and Kamm, Robert W.: Multiengine Airplane Spin Characteristics as Indicated by Model Tests in the Free-Spinning Wind Tunnel. NACA ARR, July 1942.

4. Pearson, H. A., and Garvin, J. B.: Velocity Gained and Altitude Lost in Recoveries from Inclined Flight Paths. NACA TN No. 829, 1941.

5. Rhode, Richard V.: The Pressure Distribution over the Wings and Tail Surfaces of a PW-9 Pursuit Airplane in Flight. NACA Rep. No. 364, 1930.

6. Scudder, N. F., and Miller, M. P.: The Nature of Air Flow about the Tail of an Airplane in a Spin. NACA TN No. 421, 1932.

7. Sears, Richard I., and Hoggard, H. Page, Jr.: Characteristics of Plain and Balanced Elevators on a Typical Pursuit Fuselage at Attitudes Simulating Normal-Flight and Spin Characteristics. NACA ARR, March 1942.

8. McAvoy, William H.: Maximum Forces Applied by Pilots to Wheel-Type Controls. NACA TN No. 623, 1937.

TABLE I

RECOVERIES FROM LEFT SPINS FOR DOUGLAS DC-3 MODEL

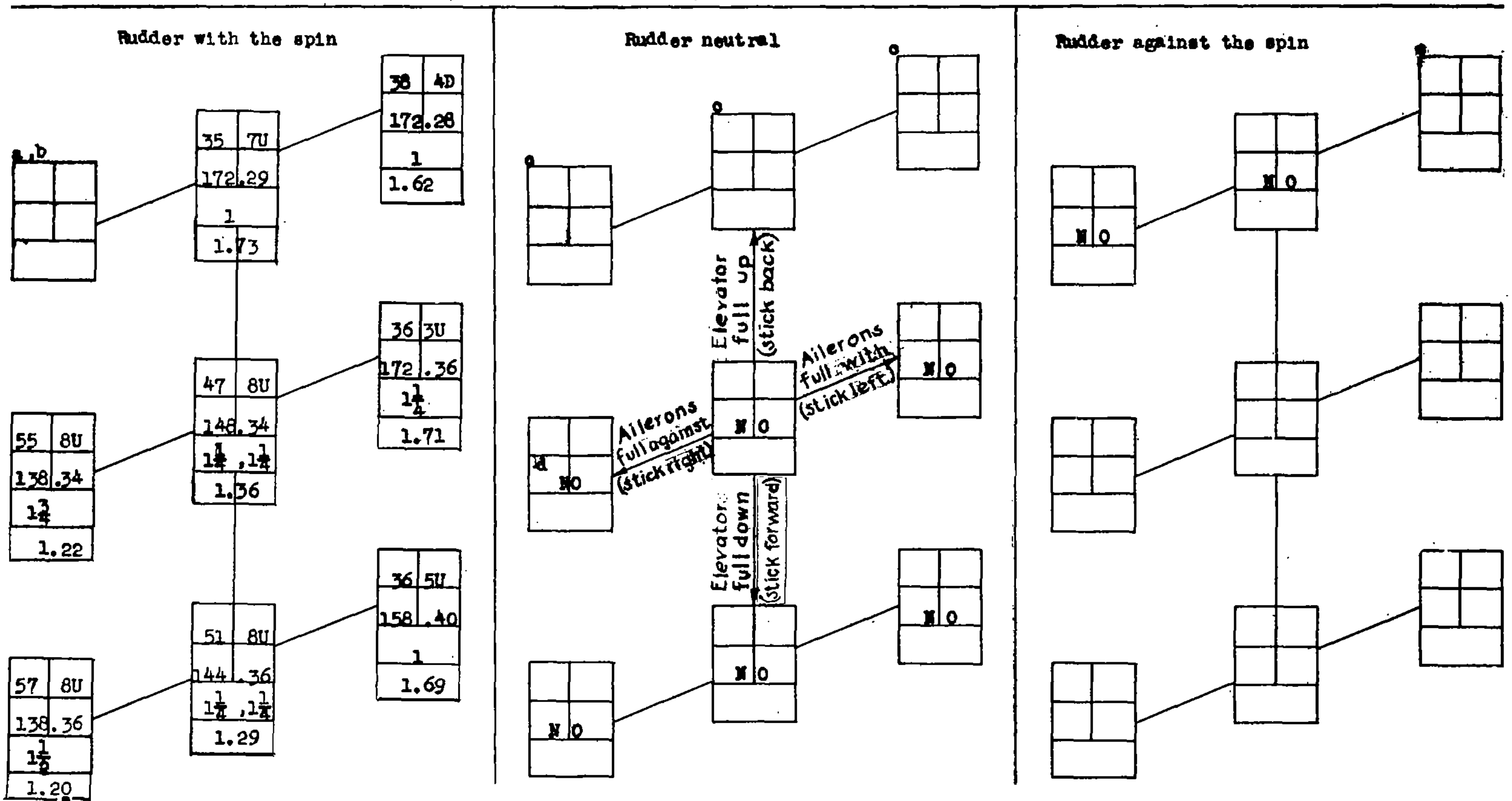
[Altitude, 10,000 ft; all tests made with mass added along fuselage, ΔI_Y and $\Delta I_Z = 0.25\ I_Y$]

Control setting (deg)					Turns for recovery
Ailerons		Rudder		Elevator	
Right	Left	Initial	Final		
0	0	[a]30W	(b)	0	$7\frac{1}{2}$
[c]15D	25U	30W	(b)	30U	More than $5\frac{1}{2}$
15D	25U	30W	(b)	20D	$3\frac{1}{2}$
25U	15D	30W	(b)	30U	More than 4
25U	15D	30W	(b)	20D	8

[a]W indicates with the spin.
[b]Recovery attempted by releasing the rudder.
[c]D indicates down; U, up.

Chart 1. - Effect of Controls on Spin and Recovery Characteristics of DC-3 Model

[Normal loading; landing gear retracted; flaps neutral; recovery by rapid full rudder reversal (steady-spin data obtained for rudder setting indicated); left erect spins; equivalent test altitude, 10,000 ft]



[a]Too oscillatory to test.
[b]For rudder deflection increased to ±35 deg, recovery required one-half turn.
[c]Went into steep spiral with high rate of descent.
[d]NO indicates model would not spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	
Load factor	

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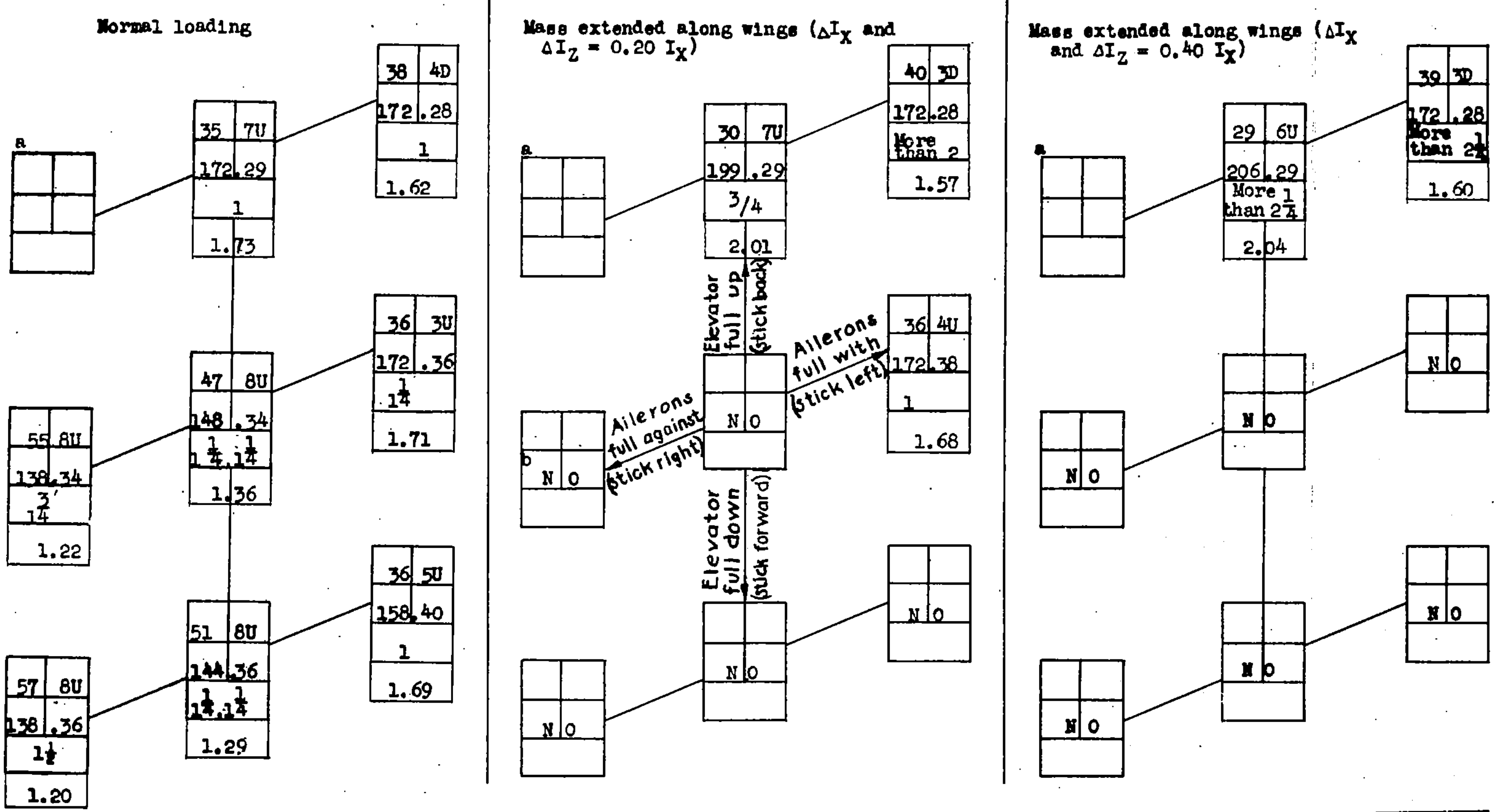
Chart 2. - Effect of Mass Distribution on Spin and Recovery Characteristics of DC-3 Model.

[Loading as indicated; landing gear retracted; flaps neutral; recovery by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-with spins); left erect spins; equivalent test altitude, 10,000 ft]



[a] Too oscillatory to test.
[b] NO indicates model would not spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	
Load factor	

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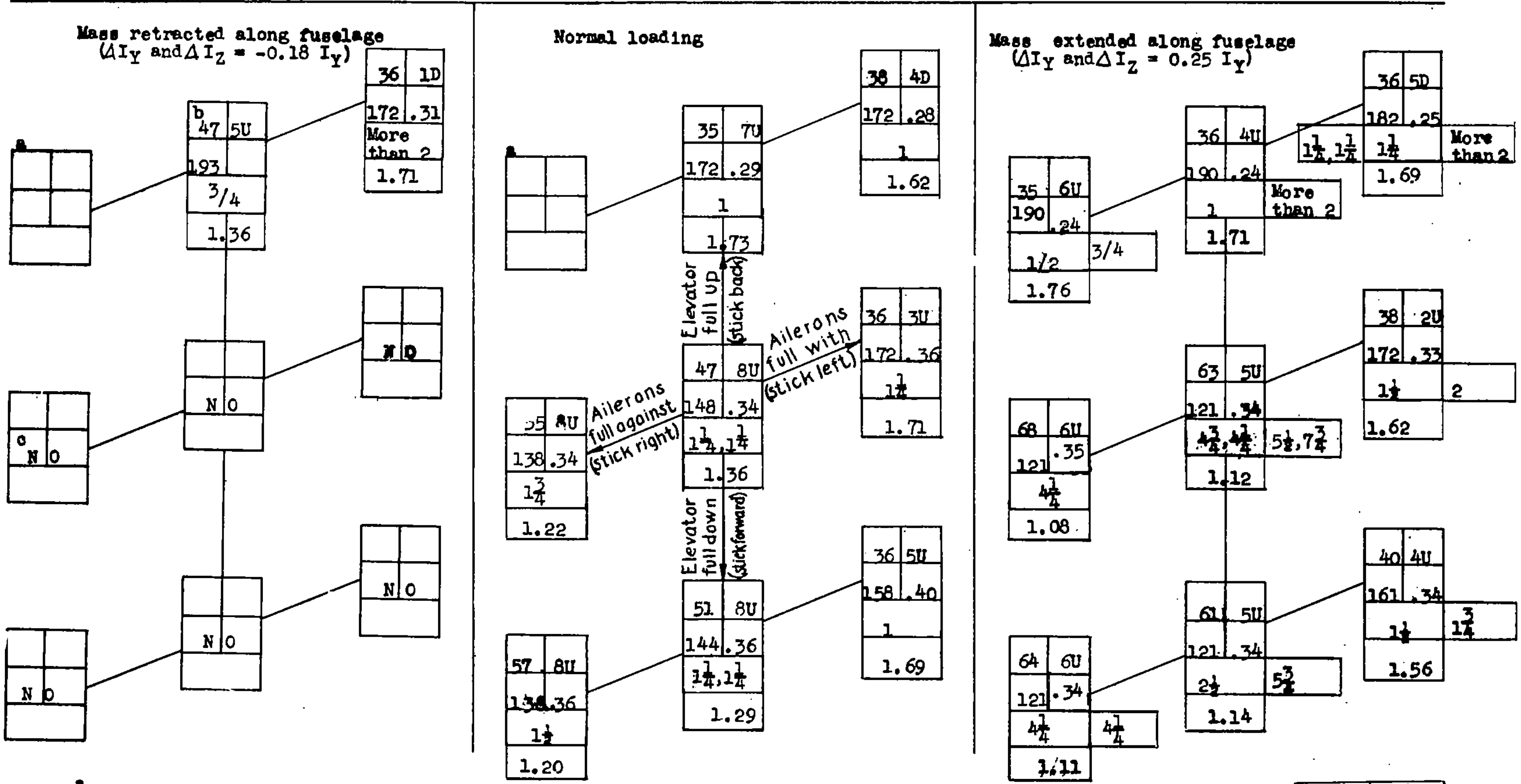
Chart 3. - Effect of Mass Distribution on Spin and Recovery Characteristics of DC-3 Model

[Loading as indicated; landing gear retracted; flaps neutral; recovery attempted from, and steady-spin data presented for, rudder-with spins; left erect spin; equivalent test altitude, 10,000 ft]



[a] Too oscillatory to test.
[b] Oscillates in pitch; average value given.
[c] NO indicates model would not spin.
[d] Turns for recovery by rapid movement of the rudder and elevator to neutral.
[e] Recovery attempted by rapid movement of the rudder to full against the spin.
[f] Turns for recovery by rapid movement of the rudder to neutral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

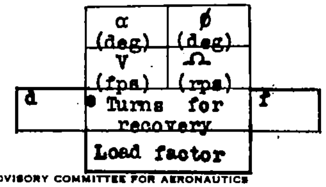


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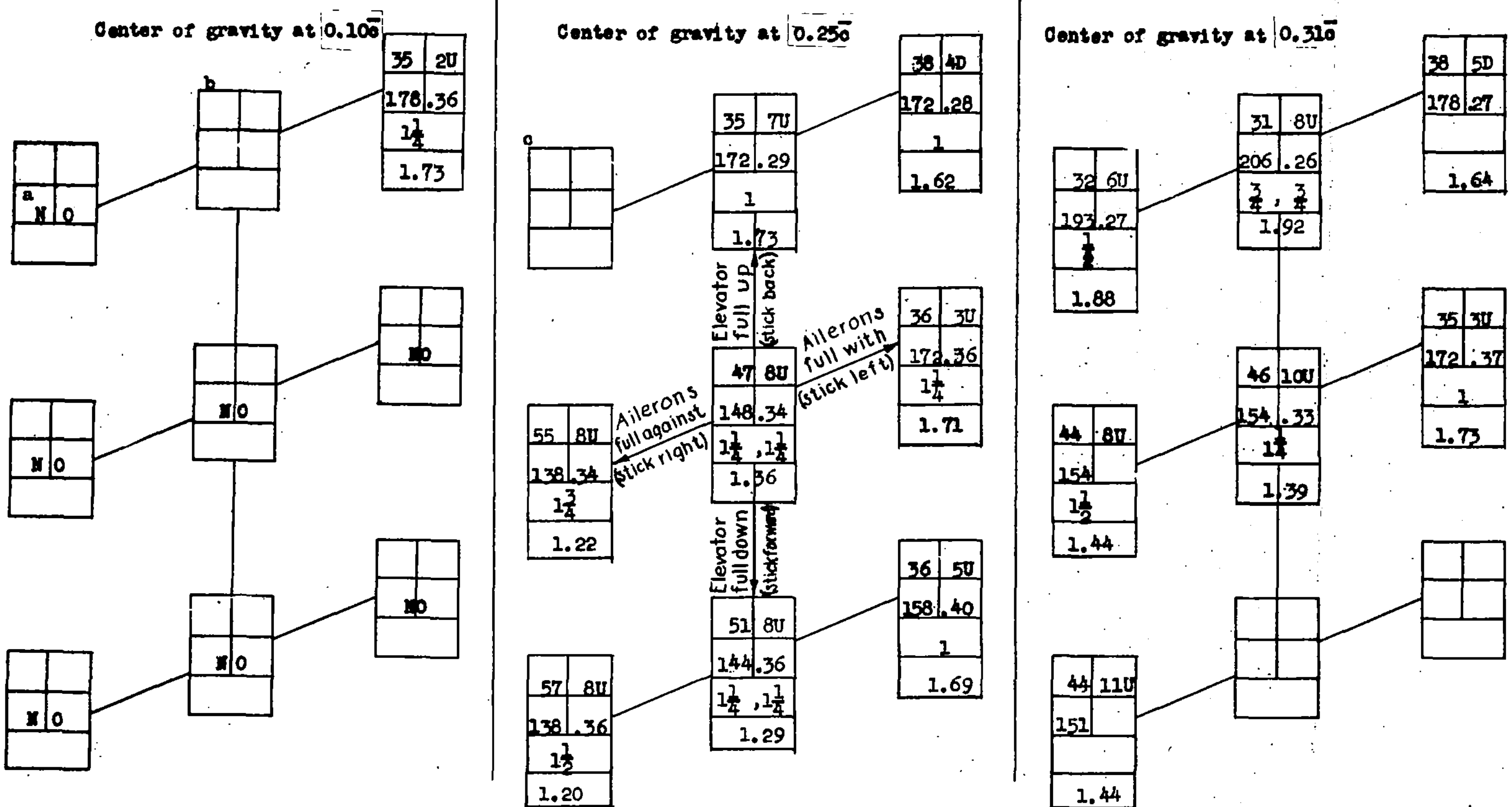
Chart 4. - Effect of Center-of-Gravity Location on Spin and Recovery Characteristics of DC-3 Model

[Center-of-gravity location as noted; landing gear retracted; flaps neutral; recovery by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-with spins); left erect spins; equivalent test altitude, 10,000 ft]



[a]NO indicates model would not spin.
[b]Steep spin or spiral with high rate of descent.
[c]Too oscilatory to test.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	
Load factor	

Chart 5. - Effect of Controls, Center-of-Gravity Location, and Mass Distribution on Spin and Recovery Characteristics of DC-3 Model

[Loading, "preliminary normal" except as indicated; landing gear retracted; flaps neutral; recovery by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins; ailerons neutral for all tests; equivalent test altitude, 2500 ft]

		Rudder with the spin (Two types of spin)	Rudder neutral	Rudder against the spin	Center of gravity at $0.10\bar{c}$	Center of gravity at $0.19\bar{c}$	Center of gravity at $0.30\bar{c}$	Mass added along wings (ΔI_X and ΔI_Z = $0.23\ I_X$)	Mass added along fuselage (ΔI_Y and ΔI_Z = $0.40\ I_Y$)	Mass added along fuselage (ΔI_Y and ΔI_Z = $0.28\ I_Y$) and center of gravity at $0.33\bar{c}$
Elevator full up (stick back)	α (deg)	26 / 36	[b]	NO	NO	30	35	24	36	38
	φ (deg)	9U / 3U				5U	3U	6U	0	0
	V (fps)	202 / 164				206	171	219	172	158
	Ω (rps)	.30 / .29					.25		.23	.20
	Turns for recovery	$\frac{1}{2}$ / $\frac{3}{4}$				$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$		1, $\frac{3}{4}$
	Load factor	2.29 / 1.70				1.99	1.73	2.42	1.68	1.62
	α (deg)	[a] NO	NO	NO	NO	NO	NO	NO	39	55
	φ (deg)								8U	3U
	V (fps)								144	127
	Ω (rps)								.31	.29
	Turns for recovery								1,1	$1\frac{1}{4}$
	Load factor								1.60	1.22
Elevator full down (stick forward)	α (deg)	NO	NO	NO	NO	NO	NO	NO	40	51
	φ (deg)								6U	5U
	V (fps)								138	131
	Ω (rps)								.32	.30
	Turns for recovery								$\frac{1}{2}$	$1\frac{1}{2}$, $1\frac{1}{2}$
	Load factor								1.54	1.29

Key to each block:

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	
Load factor	

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

[a] NO indicates model would not spin.
[b] Too oscillatory to test.

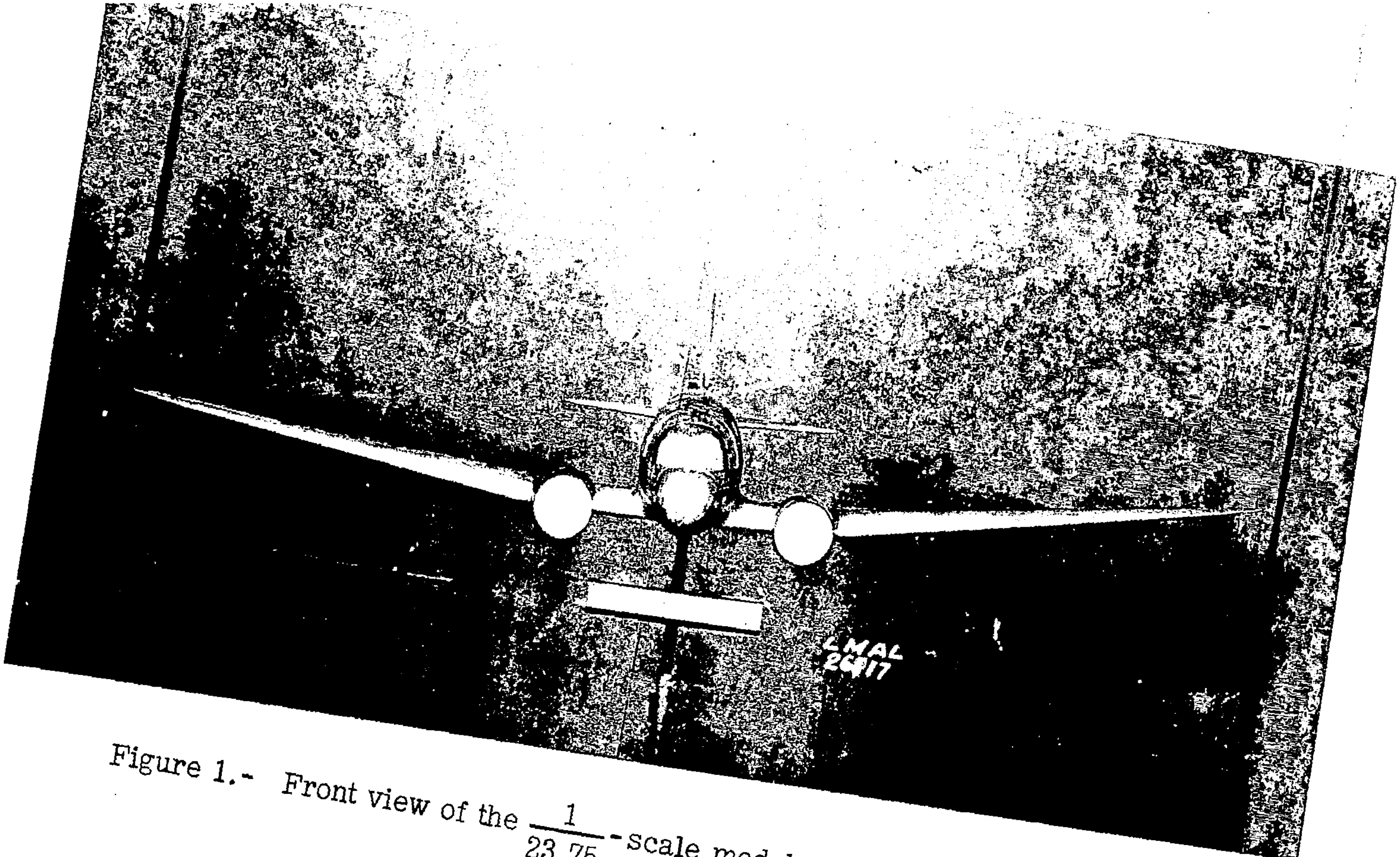


Figure 1.- Front view of the $\frac{1}{23.75}$-scale model of the Douglas DC-3 airplane.

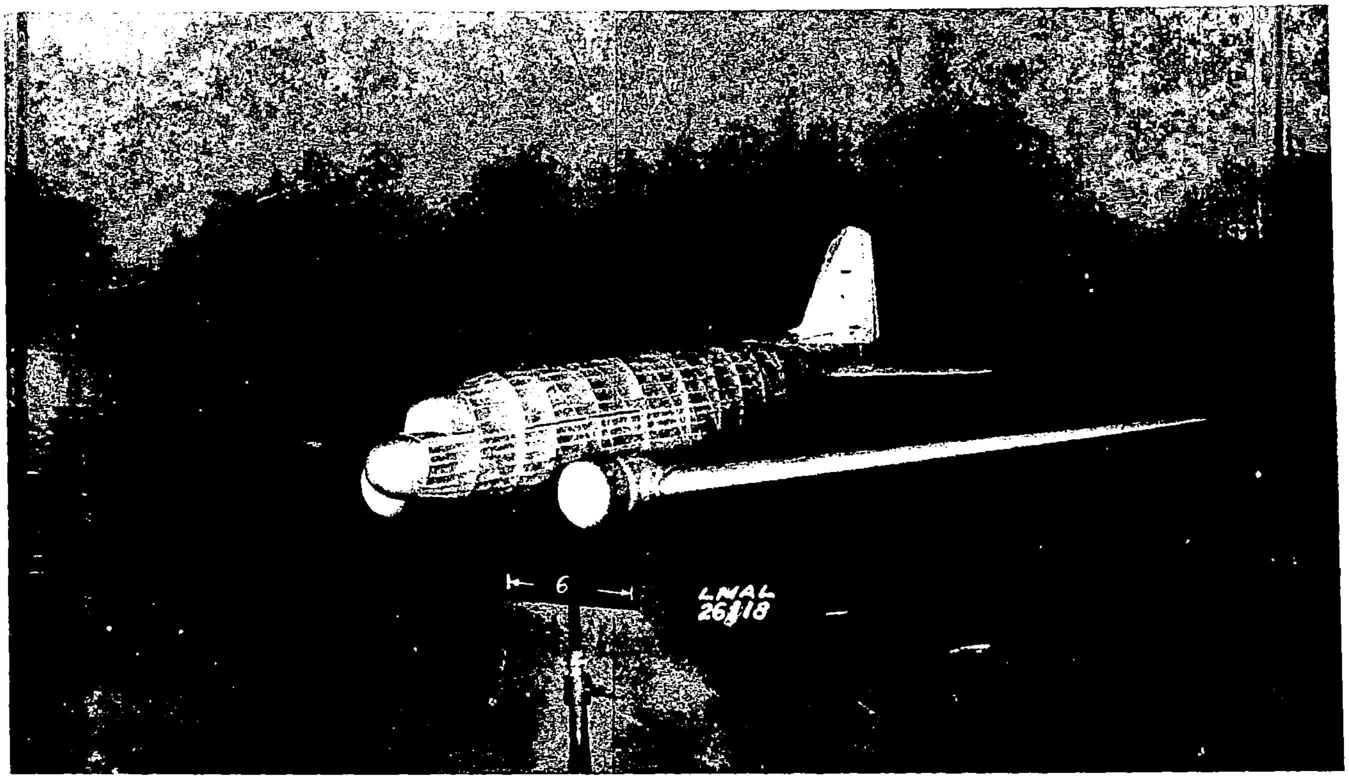


Figure 2.- Three-quarter front view of the $\frac{1}{23.75}$-scale model of the Douglas DC-3 airplane.

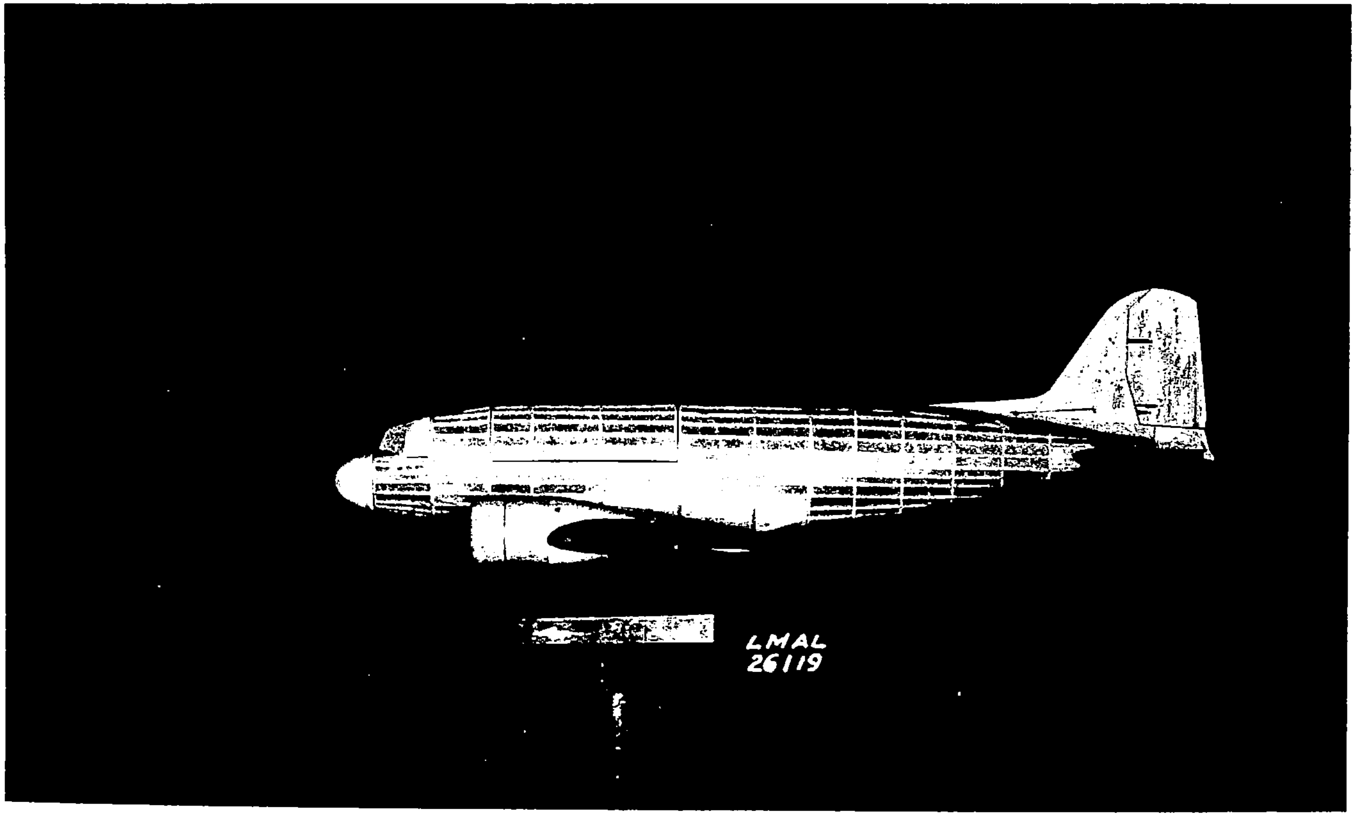


Figure 3.- Side view of the $\frac{1}{23.75}$-scale model of the Douglas DC-3 airplane.

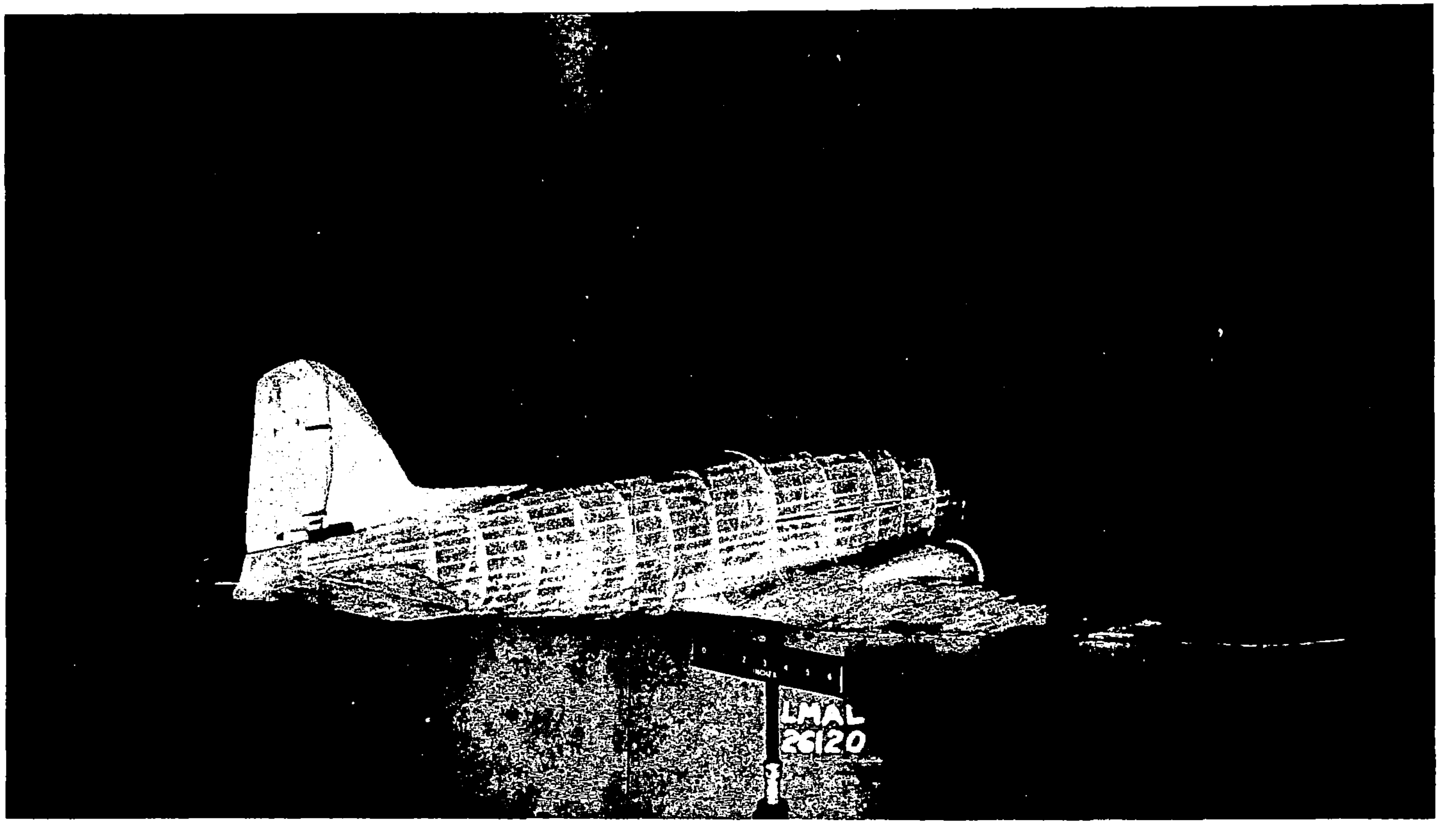


Figure 4.- Three-quarter rear view of the $\frac{1}{23.75}$-scale model of the Douglas DC-3 airplane.

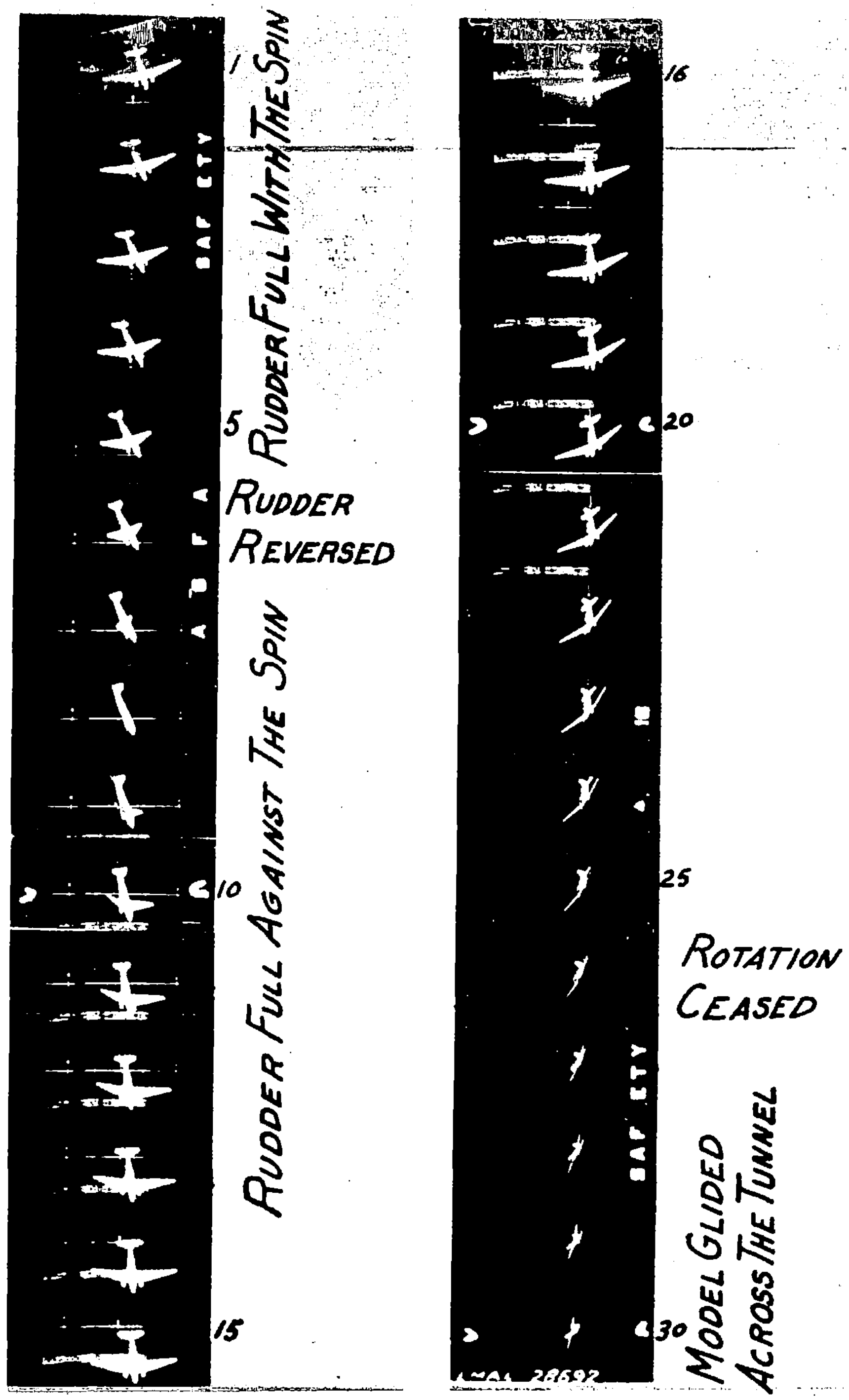


Figure 5.- Recovery from an elevator-up spin. Control settings: rudder as noted, elevator full up, ailerons neutral. Recovered in $\frac{1}{2}$ turn (frames 6 to 26).

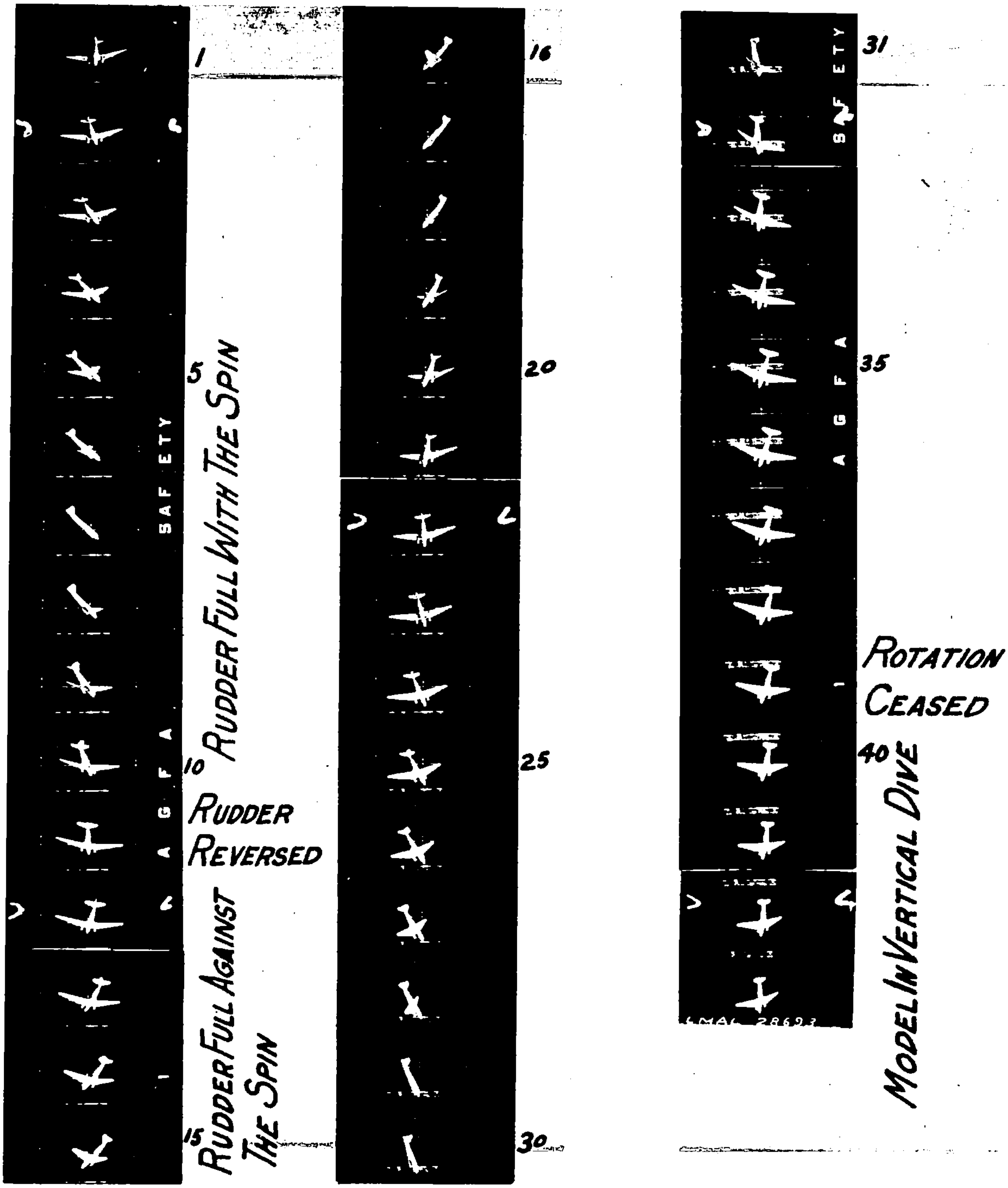


Figure 6.- Recovery from an elevator-neutral spin. Control settings: rudder as noted, elevator neutral, ailerons neutral. Recovered in 1 turn (frames 11 to 39).

Figure 7.- Recovery from an elevator-down spin. Control settings: rudder as noted, elevator full down, ailerons neutral. Recovered in $1\frac{1}{4}$ turns (frames 6 to 37).

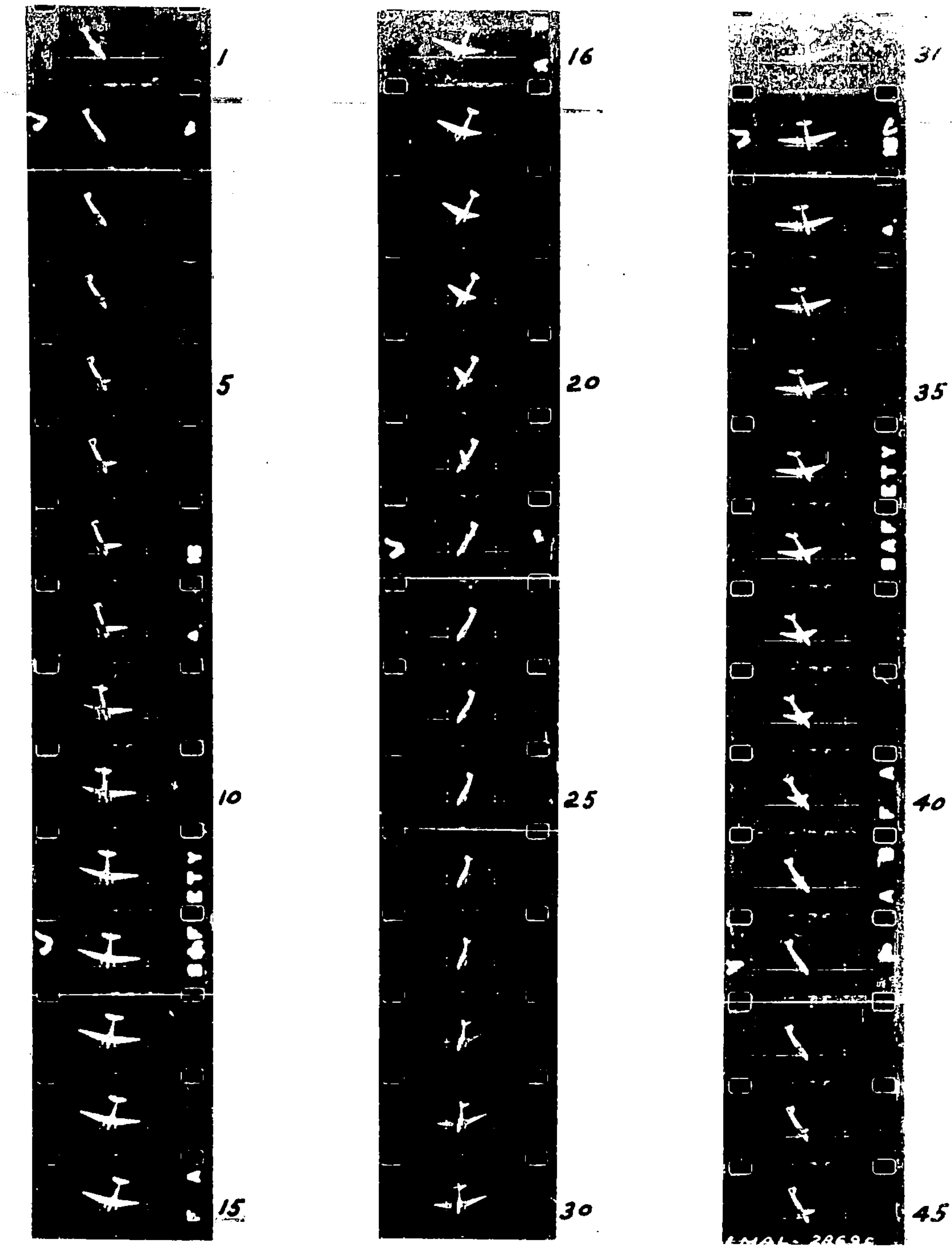
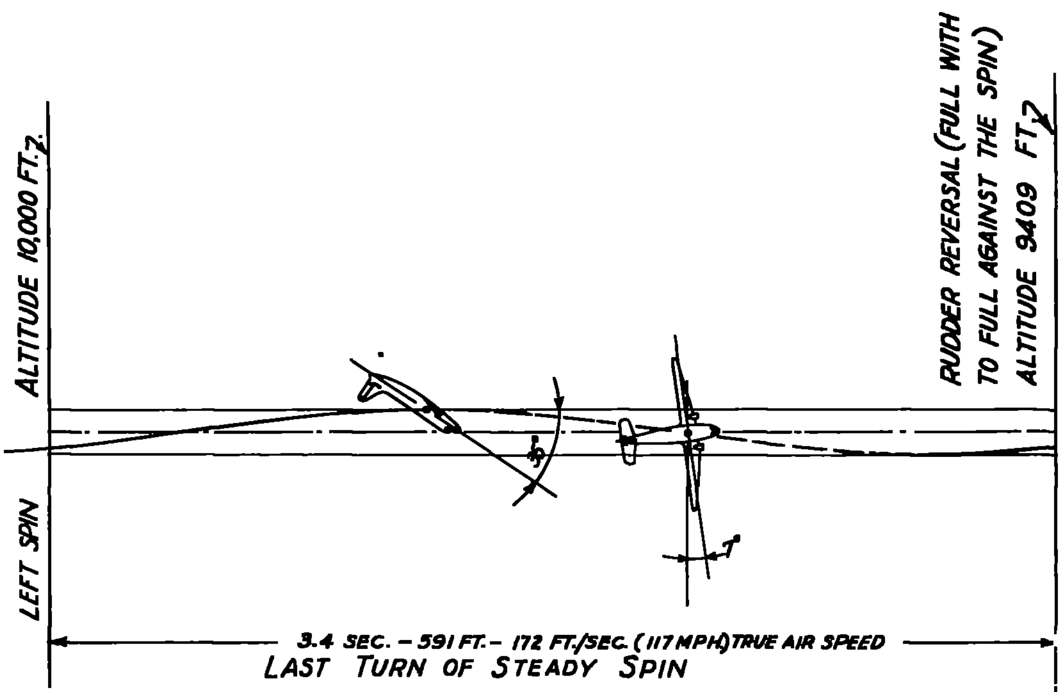


Figure 8.- Typical steep spin. Control settings: rudder full with the spin, elevator full up, ailerons neutral. Full-scale values: $\alpha = 35^{\circ}$, $\phi = 7^{\circ}$, V = 172 ft/sec (117 mph), radius of spin = 13.6 ft, Ω = 0.29 rev/sec.



RUDDER FULL WITH, ELEVATOR FULL UP, AILERONS NEUTRAL

FIG. 9 – STEADY SPIN AND RECOVERY OF DC-3

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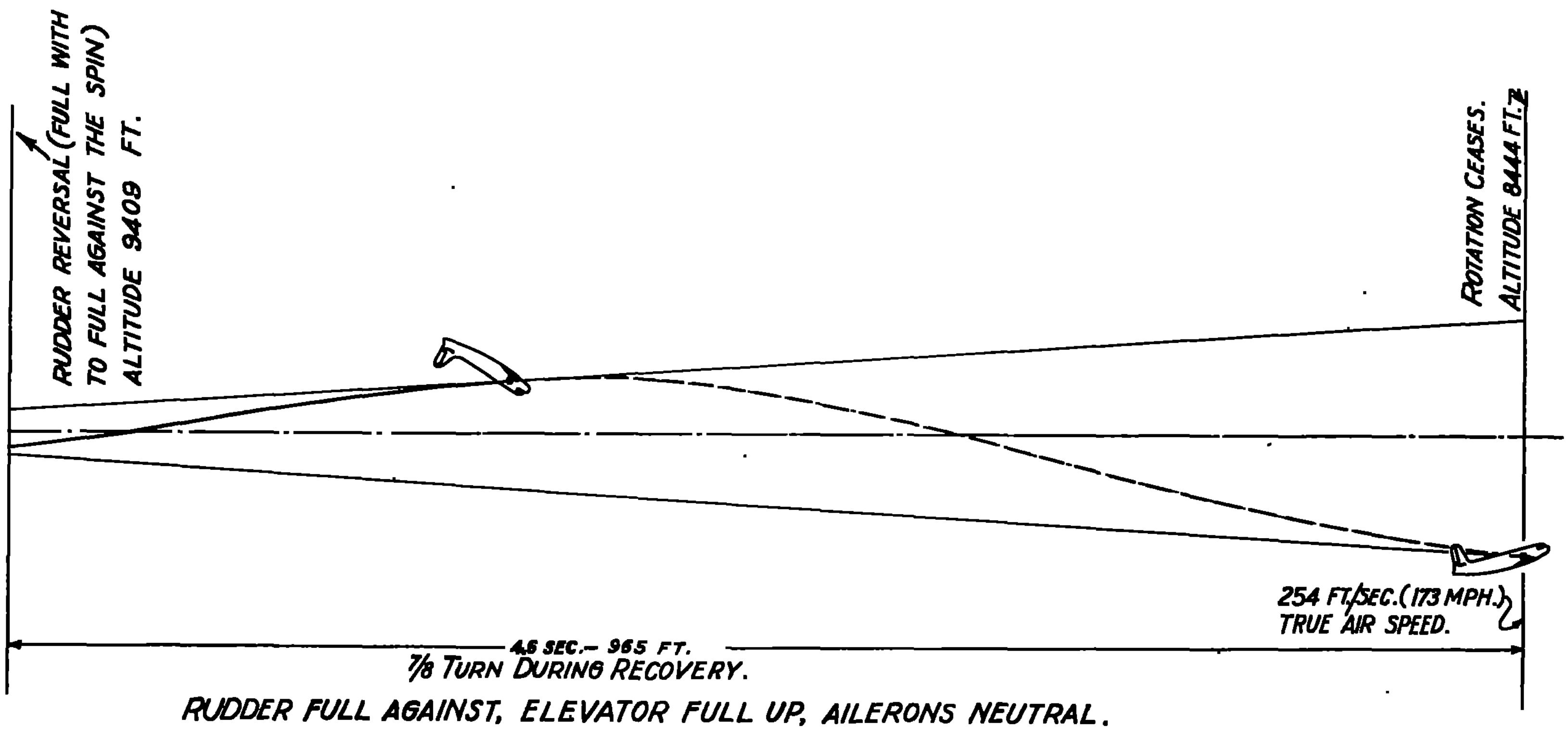

FIG. 9-(CONT.)- STEADY SPIN AND RECOVERY OF DC-3

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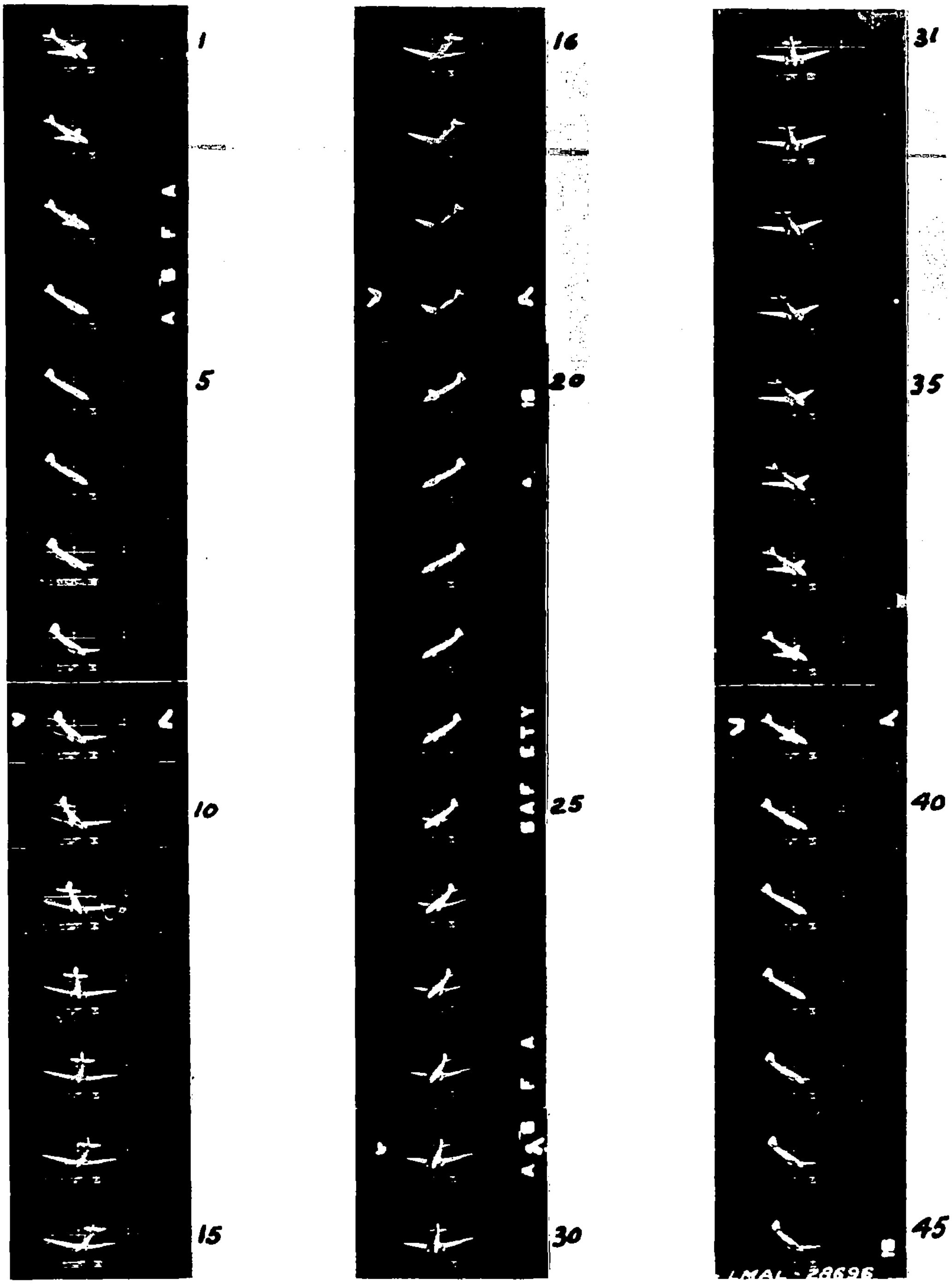

Figure 10.- Typical flat spin. Control settings: rudder full with the spin, elevator neutral, ailerons neutral. Full-scale values: α = 63°, ϕ = 5°, V = 121 ft/sec (82 mph), Ω = 0.34 rev/sec, radius of spin = 3.5 ft.

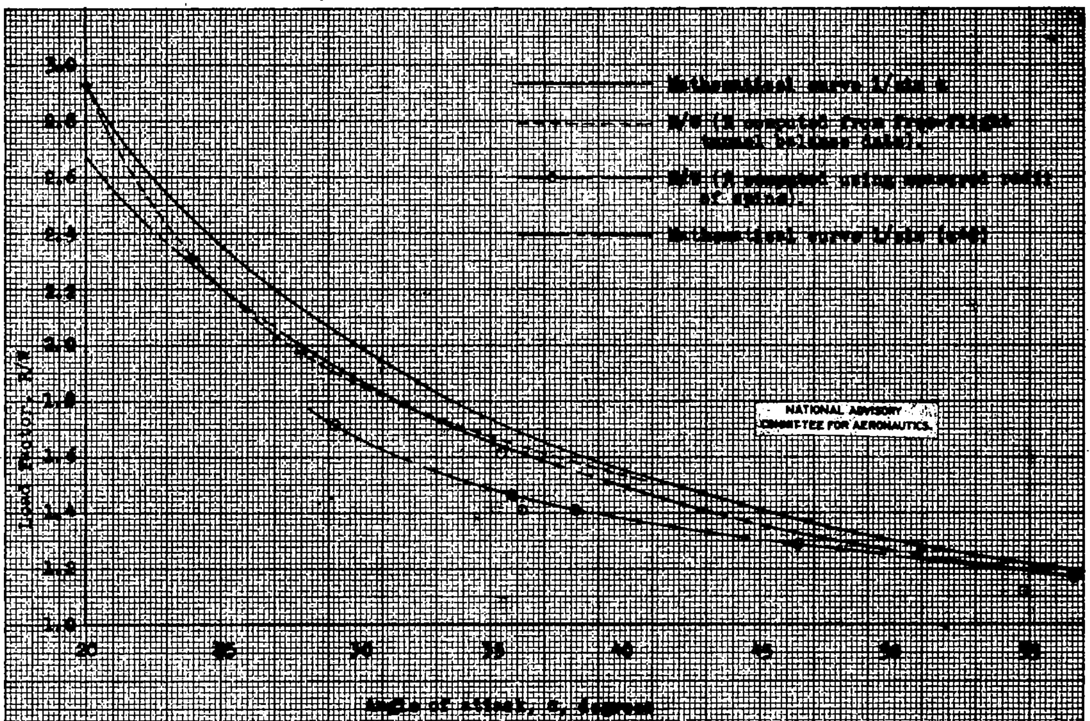

Figure 11. - Variation of load factor with angle of attack for the [illegible]-3 model.

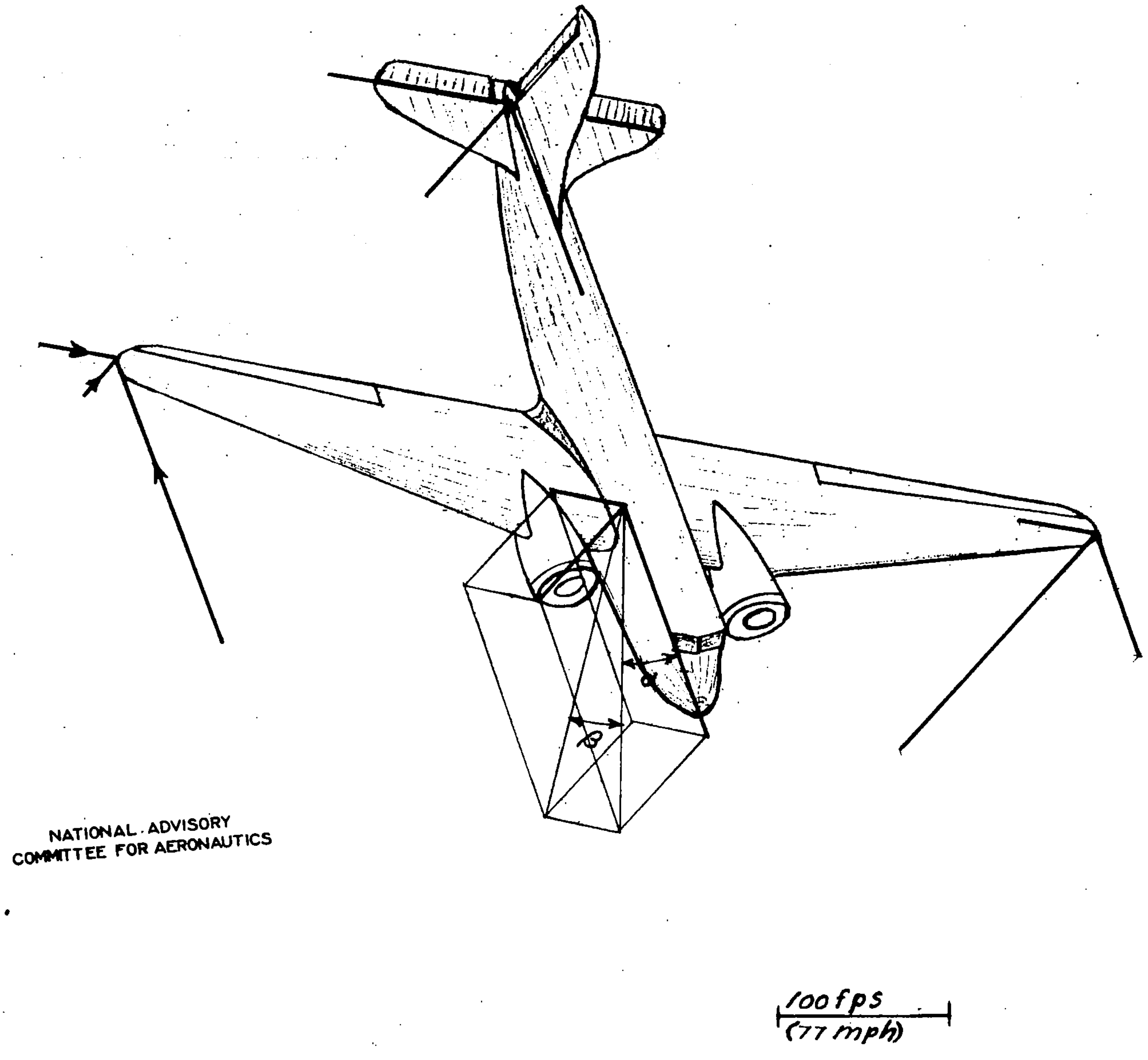

Figure 12. - Components of relative wind at center of gravity, wing tips, and tail assembly of the DC-3 model during steady left spin shown in figures 8 and 9.